Fourth Annual Conference on Carbon Capture & Sequestration

Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date

Capture and Separation - Oxyfuel Combustion

Decarbonized Electricity Production from Coal by Means of Oxygen Transport Membranes

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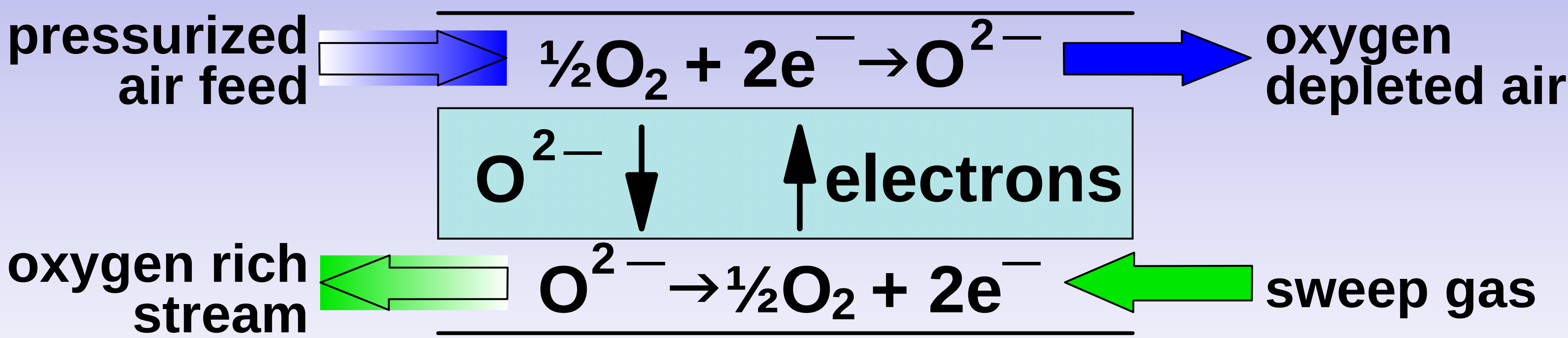
May 2-5, 2005, Hilton Alexandria Mark Center, Alexandria Virginia

OXYFUEL COMBUSTION

- **This strategy implies using pure oxygen to burn a fossil fuel**
- **Combustion products mainly consist of CO_2 and water, the latter easily removed by condensation**
- **Oxygen supplied from cryogenic ASU (no or little integration with the power plant)**
- **Oxygen from transport membranes (integration required with the power plant)**

OXYGEN TRANSPORT MEMBRANES

- Non-porous ceramic membranes, able to separate pure oxygen by the following mechanism

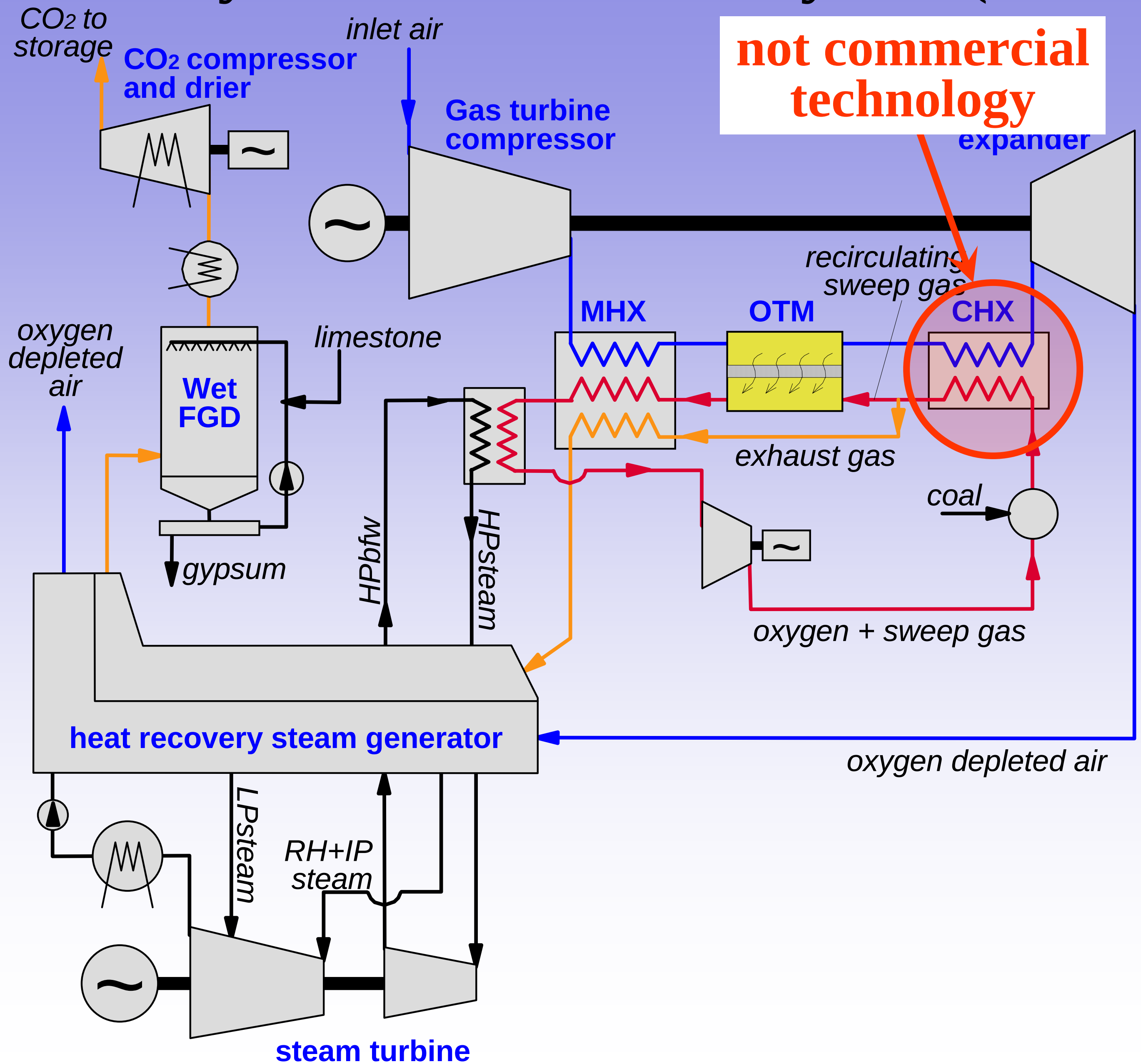


- Not yet commercial technology but at an advanced development stage

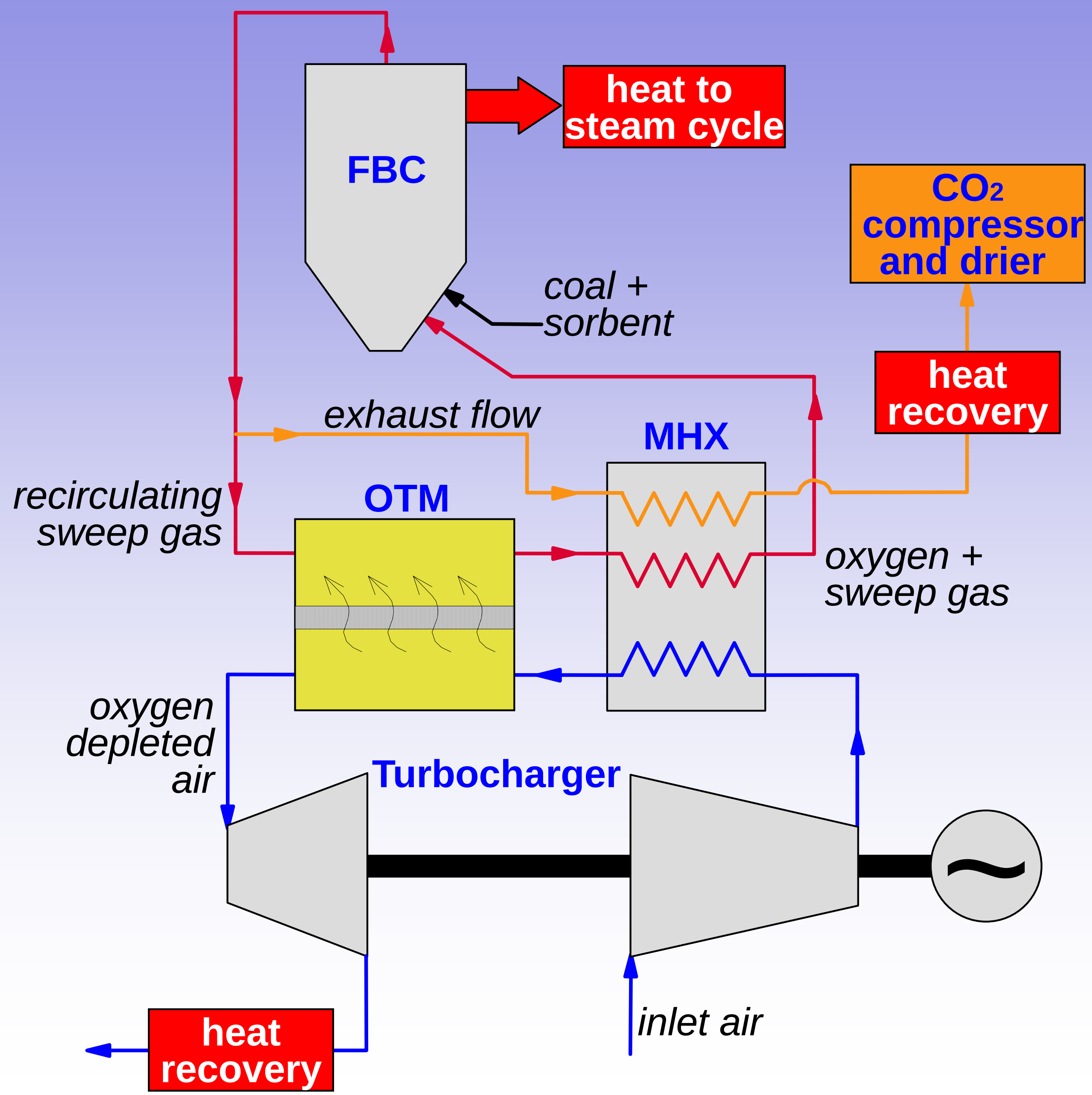
OXYGEN TRANSPORT MEMBRANES

- Operating temperature in the range 800÷1000°C.
- Conditions of the streams exiting the membranes:
  - high temperature, high pressure oxygen depleted air stream
  - high temperature oxygen rich stream
- <u>High temperature and pressure streams require tight integration with the power section to recover energy and warrant high conversion efficiency</u>

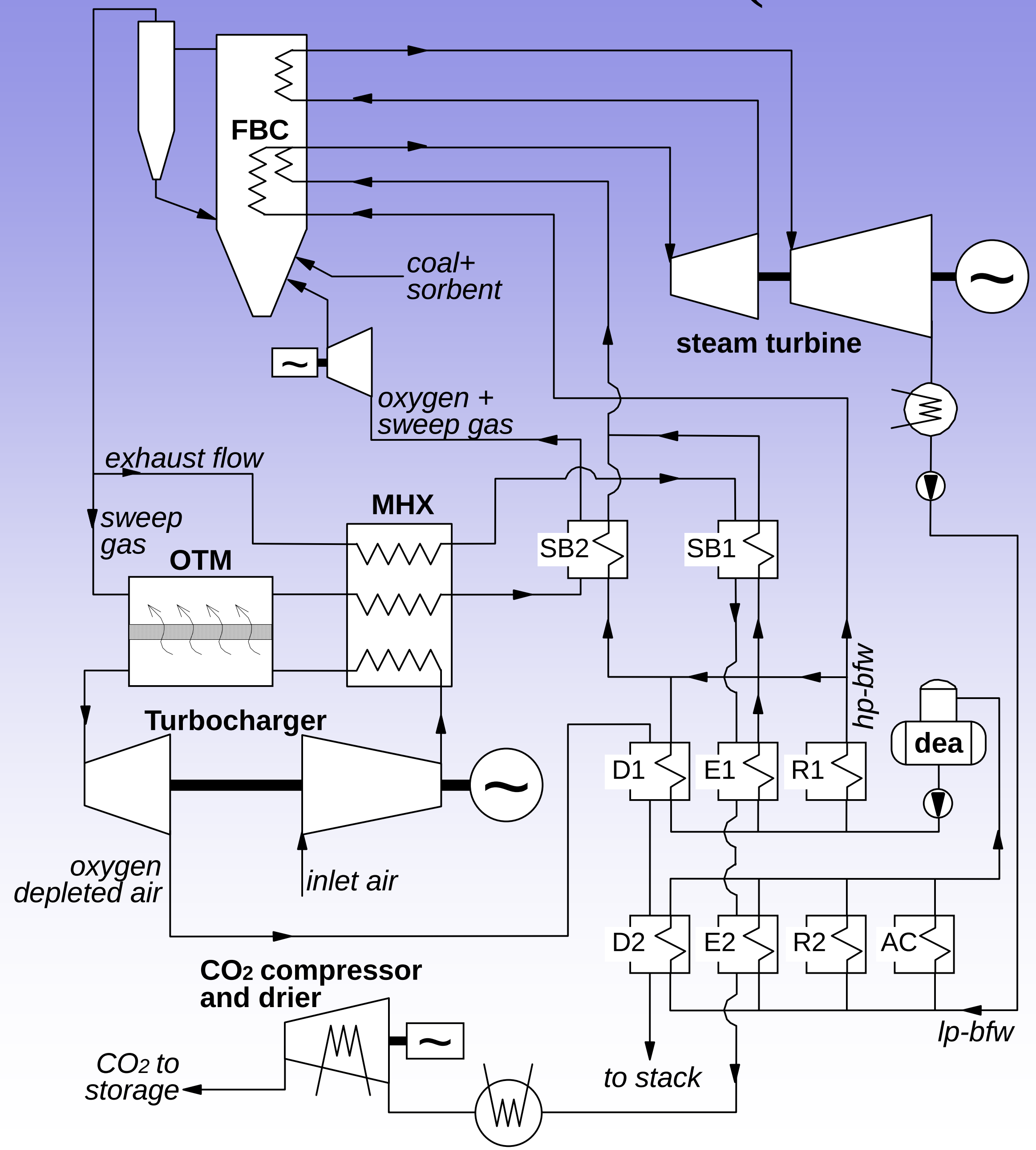
Externally Fired Combined Cycles (EFCC)



Fluidized bed combustion USC (basic scheme)



Fluidized bed combustion USC (detailed scheme)



Calculation methodology and assumptions

Thermal balances of all the plants considered have been calculated by means of a computer code developed at Politecnico di Milano

Main assumptions required to performance estimation:

EFCC:	gas turbine inlet mass flow rate: 644 kg/s
	turbine inlet temperature: 1050÷1350 °C
	3 pressure level + RH HRSG
	sweep gas backpressure: 3 bar
FBC-USC:	steam SH conditions: 250 bar, 600 °C
	steam RH conditions: 60 bar, 610 °C
	FBC temperature: 860 °C
	FBC pressure: 1.15 or 10 bar
Miscellaneous:	coal: Illinois#6
	O_2 content at combustor exit: 3.2%
	condensation pressure: 0.04 bar
	final CO_2 delivery pressure: 150 bar

Membrane sizing and costing

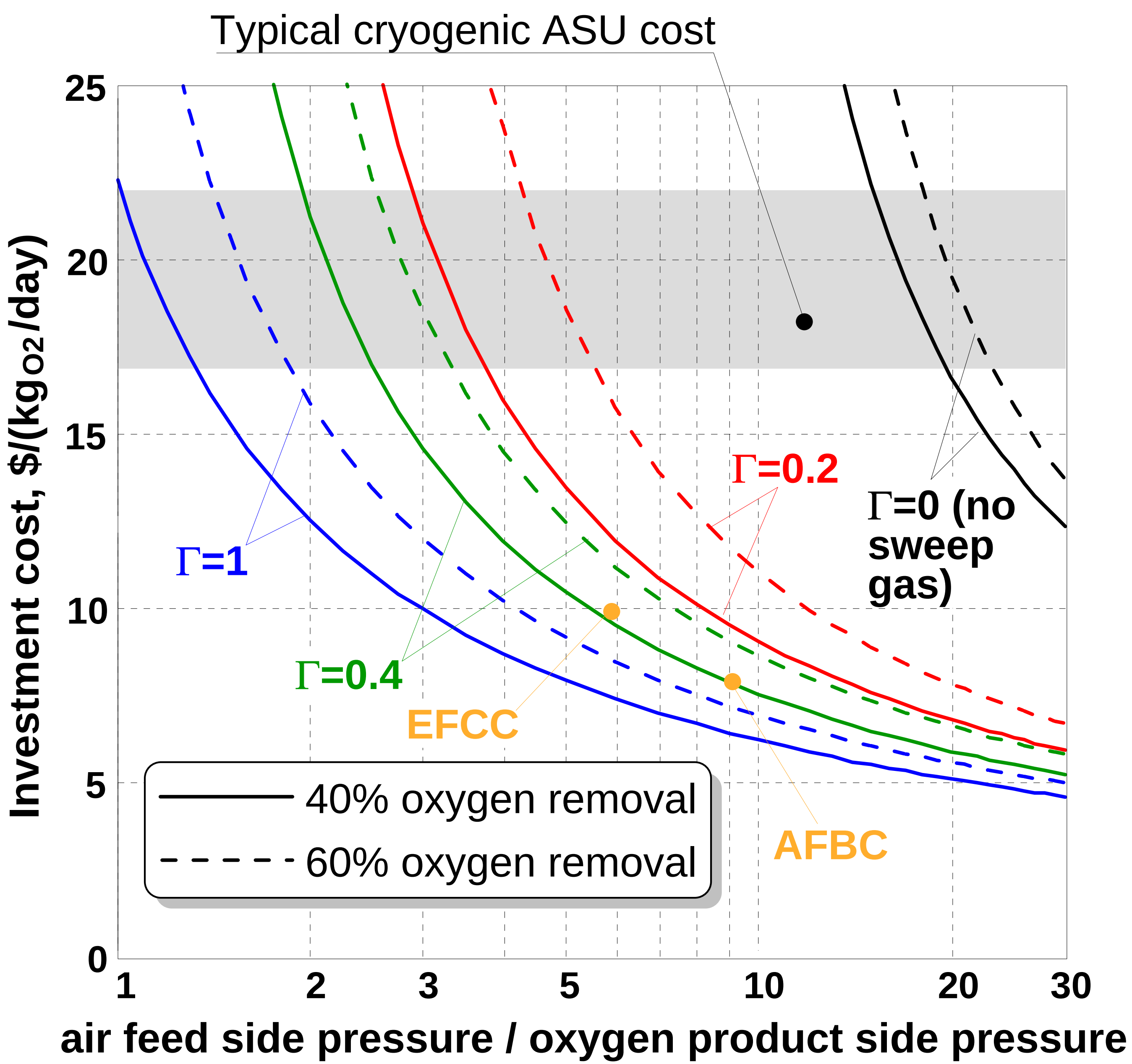
Membrane area depends on:

- Pressure ratio between air feed side and oxygen product side
- Fraction of removed oxygen (directly related to TIT in the EFCC plant)
- Flow rate of sweep gas (Γ: ratio between sweep and air feed molar flow rate)

Cost evaluation:

- Membrane area have been calculated by means of a 1-D finite differences model
- Specific membrane cost has been calibrated on various IGCC cases presented in the literature and assuming a 25% cost reduction compared to the corresponding cryogenic ASU

Membrane sizing and costing



EFCC performance calculation

TIT, °C	1050	1150	1250	1350
Coal LHV input, MW	528.5	564.1	586.5	628.8
GT pressure ratio	9.0	11.7	14.3	17.0
GT power output, MW	145.3	167.5	184.6	198.5
ST power output, MW	116.5	123.4	125.5	141.7
Net power output, MW	237.5	264.8	283.0	309.7
Net plant LHV efficiency, %	44.94	46.95	48.24	49.25

Results based on an assigned gas turbine inlet mass flow rate of 644 kg/s

FBC-USC performance calculation

FBC pressure, bar	1.15	10
Coal LHV input, MW	984.9	984.9
Turbocharger inlet air flow, kg/s	593.5	698.2
Turbocharger pressure ratio	11	20
Turbocharger power output, MW	74.7	69.7
ST power output, MW	404.9	400.6
Net power output, MW	407.2	412.6
Net plant LHV efficiency, %	41.34	41.89

Comparison with other technologies

	USC Rankine cycle			IGCC Quench		EFCC
	Benson boiler	Cryogenic oxyfuel	FBC + OTM	No capture	Selexol CO_2 capture	OTM
LHV coal input, MW	985.0	985.0	985.0	908.2	983.7	528.5
Net power output, MW	440.1	348.5	407.2	390.1	361.9	237.5
Net LHV efficiency, %	44.68	35.38	41.34	42.95	36.79	44.94
CO_2 capture efficiency, % of fuel C	0	100	100	0	91.28	100
Specific CO_2 emissions, g/kWh	729	0	0	752	70.1	0

Economic analysis

Main assumptions:

- Capital charge rate: 15% per year
- Capacity factor: 7000 h/y
- Coal price: 1.5 $/GJ
- Interest during construction: 12.3%
- Annual O&M: 3% of the plant cost
- CO_2 disposal: 5 $/tonne
- Yearly efficiency penalty: 2%

	USC Rankine cycle			IGCC Quench		EFCC
	Benson boiler	Cryogenic oxyfuel	FBC + OTM	No capture	Selexol CO_2 capture	OTM
Overnight capital cost, $/kWh	1184	1917	1650÷1900	1187	1531	1500÷1800
COE: Capital, ¢/kWh	2.85	4.61	3.97÷4.57	2.86	3.68	3.61÷4.33
COE: O&M, ¢/kWh	0.51	0.82	0.71÷0.81	0.51	0.66	0.64÷0.77
COE: Fuel, ¢/kWh	1.23	1.56	1.33	1.28	1.50	1.23
COE: CO_2 disposal, ¢/kWh	0.00	0.47	0.40	0.00	0.41	0.37
COE: Total, ¢/kWh	4.59	7.46	6.41÷7.12	4.65	6.25	5.85÷6.70
Cost of CO2 captured*, $/tonne		30.6	22.7÷31.5		20.1	17.0÷28.5
Cost of CO2 avoided*, $/tonne		38.6	24.5÷34.0		25.0	16.9÷28.4

US dollars valued in 2002

* with respect to USC base case power plant

CONCLUSIONS

- OTM allows to arrange low (or zero) CO_2 emissions oxyfuel power plants having substantially higher efficiency than the competing technologies.
- Preliminary economic analysis shows that the cost of electricity can be competitive with respect to other low CO_2 emissions technologies.
- Previous advantages can be achieved only through a tight membrane-cycle integration and plant design optimization
- Realization of EFCC cycles **relies on** the availability of high temperature ceramic heat exchangers (<u>major technological hurdle</u>)
- Use of sweep gas greatly helps to reduce membrane area and cost. <u>Gas filtration can be a secondary technological hurdle</u> (for both EFCC and FBC-USC)